COMPUTING, INFORMATION AND COMMUNICATION TECHNOLOGIES (CICT)

Intelligent Systems Proposal - FY 03

Science Goal Monitor: Tools for Science Goal Capturing and Onboard Goal Monitoring

Abstract

Upcoming astronomical space-based observatories face many of the same information hurdles as deep-space, Earth, or Sun oriented missions: the need to dramatically increase onboard automation and to effectively and efficiently handle an exponentially increasing volume of scientific data.

Two long-standing paradigms for astronomical observatories must be changed in order to achieve significant increases in scientific return: (1) that the observing schedule and scientific processing can only be managed on the ground with significant human interaction, and (2) that all scientific data is downloaded and archived regardless of its scientific value. These paradigms have been acceptable until now because onboard computing has not been capable of permitting significant onboard science analysis nor have the rate of scientific data recording thus far exceeded the download capacities and/or cost thresholds. For upcoming generations of observatories, significant costs savings and increased science return could be obtained by developing onboard science analysis and selective data downloading.

In order for this concept to be realized, we must be able to capture and interpret the *science* goals of an astronomical observing program, be able to interpret those goals in machine interpretable language, so that spacecraft can autonomously react in consideration of the scientist's goals. In addition, both scientists and engineers must understand what capabilities are needed onboard for success. Further, metrics must be developed to realistically understand the potential increase in science returns and the risks involved in onboard analysis, and the costs to develop a production-ready system (both software and hardware).

We propose to develop the Science Goal Monitor (SGM) with the objective of a) prototyping user interfaces to capture science goals in a fashion that the scientist can use and understand, b) evaluating existing and emerging software to dynamically evaluate science data on board the spacecraft, and c) providing a simulation framework that astronomical missions can use in their early conceptual design phases to understand and predict the effectiveness of a SGM on their missions.

We have developed a team that includes active astronomers and software engineers currently involved in both space-based and ground-based observing. We will focus on astronomical monitoring projects of inherently varying targets to develop out prototype SGM. Initially, SGM will be developed to run in a simulation mode to develop its analytical and reactive abilities. Once we have the baseline developed, we plan to implement a working prototype and test it in live observing conditions using Yale University's SMARTS (Small and Medium Aperture TelecopeS) project to compare the scientific results with their scheduling and analysis systems.

Principal Investigator

Name: Jeremy Jones

Address: Code 588, NASA GSFC

	Greenbelt, MD 20771
Organization:	GSFC 588
Telephone:	301-286-3192
FAX:	301-286-1768
E-mail:	Jeremy.E.Jones@gsfc.nasa.gov
Position Title:	Computer Engineer

Project Goals

- Using a set of astronomically oriented scenarios, develop a working prototype science goal monitor to perform in-flight science-oriented processing, and dynamically and autonomously adjust science tasks accordingly.

- Determine realistic requirements for in-flight hardware and software, metrics for measuring the monitor's scientific effectiveness, and a costs and risks analysis for developing a production flight-ready version.

- Develop and document an initial protocol and standard for describing astronomical observing goals.

Technical Approach

Background

The original concepts for the Science Goal Monitor (SGM) have been developed by Goddard's Code 588, Advanced Architectures and Automation in collaboration with the Kronos proposal team. The Kronos mission is designed to investigate the variability of active galaxies and cataclysmic variables and has been our science partner for developing some of the science use-cases for SGM. The early requirements work related to SGM has been promising for its value and applicability to Kronos. The Kronos team was convinced that a tool like SGM would significantly boost the science returns on missions with inherently variable targets as well as reduce the costs of science operations.

Rather than offering a Kronos-specific solution, we would like to provide a testbed to provide answers which will be more broadly applicable to all missions that are considering science goal-driven automation. We have reevaluated and refocused our SGM for this proposal in the following areas: a) refocused our effort on the unique aspects of SGM relative to other known projects, b) integrated SGM's development with other existing efforts rather than duplicate development, c) put more emphasis on providing upcoming missions with a solid set of metrics to estimate the value and costs of a tools such as SGM, d) teaming with an existing ground-based observatory network (SMARTS) to give us a solid baseline for testing and evaluating SGM's effectiveness.

Our approach is a multi-phased approach that will allow us to refine an attainable set of goals and measures for our success. The first two phases are concurrent. Phase 1a will involve work with the SMARTS scientists to establish a base set of science scenarios, decision guidelines, test data, and science metrics. Phase 1b will involve the development and testing of the first major build of the SGM software. During Phase II, we will use our set of SMARTS test data to exercise and tune the SGM and measure its success against a known baseline. Phase III will involve running SGM in a live astronomical environment, first evaluating sets of live astronomical data and making recommendations. After further comparison and tuning, we hope to run SGM in a fully automated mode using an observatory in the SMARTS system. While this will be a ground-based test system, the varying nature of the monitoring programs that SMARTS performs will give us an excellent and cost effective test platform for SGM's effectiveness. At the end of each phase we will provide a software baseline and status/effectiveness reports.

Phase Ia – Refine guidelines, scenarios for parallel testing on ground-base observing (8 months, concurrent with 1b)

The primary goal of Phase 1a will be integrate and adapt SGM's goals and abilities with the SMARTS operations paradigms. We will conduct interviews with the SMARTS astronomers and staff on how they currently perform their nightly observing runs. We will focus on the criteria they use to determine the phase of the various monitored objects, i.e. how do they establish priorities and resolve conflicting priorities? Also how does the team evaluate current observing conditions and recent observing results to adjust and set the schedule for the next set of observations?

In addition, we will work with the SMARTS team to draw on their current observations and develop a solid data base of actual observing archives, along with logs and other documentation about their current scheduling processes.

Finally we will work with the SMARTS astronomers to review and establish metrics on which we can judge the effectiveness of SGM.

Phase Ib – Initial prototype development and standalone test (8 months)

Concurrently, phase 1b will be software oriented, developing and testing the initial build of SGM to run in a simulated environment. We will evaluate existing software and hardware systems in order to determine the best use of prior work while still achieving our needs. For example, we will closely examine JPL's CASPER (Continuous Activity Scheduling Planning Execution and Replanning) package, along with their ASE (Autonomous Spacecraft Environment), which are being developed for the Techsat-21 mission. Some of their features seem to be very promising for use within SGM. Additionally, we will monitor other related projects and evaluate their applicability as we progress.

We will also develop the test environment and datasets necessary to provide simulations for testing SGM's capabilities and effectiveness. While our tests for this project will use all ground-based or simulated data, we will expressly focus selection of hardware and software that uses technologies capable of being deployed on-orbit within the next 10 years.

Phase II – Test, evaluate and tune prototype performance against baseline data (8 months)

With the science and software developed in Phase I, Phase II will focus on testing and tuning our prototype SGM using canned and simulated data. This "controlled" environment will provide repeatability in testing so that we can effectively tune and improve SGM's reactive abilities, and understand and improve the quality of the metrics we use to understand SGM's scientific effectiveness.

Phase III – Test prototype in "live" observing environment (8 months)

The final phase of our project will involve adapting SGM to work in a live observing environment using one or more of the SMARTS observatories. This will involve the following steps:

- Adapt SGM's interfaces to integrate with "live" observing data from the observatory's detectors.

- Run SGM through several observation cycles with SGM interpreting the data received and making "recommendations" only. The actual decision making on the observing priorities will continue to be made by the SMARTS operations staff.

- Once both the SGM and the SMARTS teams are comfortable with the effectiveness of SGM, we plan to perform several additional observing cycles, where the decisions on observing priorities will be made by SGM itself.

- Measure the effectiveness of SGM throughout the phase using our established metrics and compare the results with our baseline expectations.

Enterprise or Mission Applicability

A major objective of the CICT IS program is to increase autonomy in upcoming NASA missions. While much effort has gone into autonomy in spacecraft operations, applying intelligent automated analyses to the science side has been relatively under-emphasized. The hardware capability to perform significant onboard science analysis is now becoming available, and the ability of space-based scientific observatories to acquire more data than can be reasonably downloaded, is coming soon. This project applies the emerging efforts to perform goal oriented onboard scheduling to the arena of astronomical missions. This potentially benefits all astronomical missions in the design and research phases from upcoming MIDEX proposals to major observatories such as the James Webb Space Telescope.

The tools we propose to develop with SGM could also be valuable for astronomical missions that are not focusing on inherently variable targets. The same onboard processing can be used to perform basic onboard analysis of images to assign download priorities and select compression techniques, allowing an observatory to reduce data download costs.

By developing and testing a prototype in a real, albeit ground-based environment, we can flexibly apply iterative, agile software development techniques to improve the prototype's performance and establish metrics to gauge its success. This will answer many unknowns about the risks and costs of developing a space-ready version of SGM.

Finally, the development of a machine interpretable standard protocol for specifying science goals will provide a baseline for later development in intelligent science-directed data systems.

Co-Investigators

Name	Title	Organization	FTE%
Sandy Grosvenor	Senior Associate	Booz Allen Hamilton	50
Dr. Anuradha Koratkar	Project Scientist	Space Telescope Science Institute	10
Karl Wolf	Senior Systems Architect	Aquilent, Inc.	50
Dr. Charles Bailyn	SMARTS team leader	Yale University	5

SMARTS scheduling/operations support (2 of them)	SMARTS post-doc types.	Yale University	10x2

Supporting Documentation

[Received via e-mail]

From: <bailyn@astro.yale.edu>
Date: Mon, 30 Sep 2002 09:46:53 -0400
To: Anuradha Koratkar <koratkar@stsci.edu>

Dear Dr. Koratkar,

I am writing to express my enthusiasm, and that of the SMARTS team, for working with you and your colleagues on testing your Science Goal Monitor and associated software on SMARTS operations. We are looking forward to detailed discussions on what we are doing, and how your development efforts might help us do it, and we are prepared to share observing logs and other records of our work with you. Below I give a brief description of the SMARTS project, and also the records available from the precursor YALO project, which might also be helpful. We are looking forward to this collaboration!

Yours Sincerely,

Charles Bailyn
SMARTS Principal Scientist
Yale University

The Small and Moderate Aperture Research Telescope System (SMARTS)

Principal Scientist: Charles Bailyn, Yale University

Participating Institutions: National Optical Astronomy Observatories
Yale University
Ohio State University
American Museum of Natural History
Georgia State University
State University of New York at Stony Brook
Space Telescope Science Institute

SMARTS is a consortium consisting of a variety of institutions which have come together to operate the existing small telescopes (aperture <2m) at the Cerro Tololo Interamerican Observatory (CTIO) in Chile. Our goal is to create a highly cost-efficient operation that will generate frontline science from these relatively small, old telescopes by enabling unique observing modes.

Our first semester of operation (2003A) starting in Feb 2003, will employ the following telescope/instrument combinations:

1.5m telescope + RC spectrograph
1.3m telescope (2MASS) + ANDICAM (dual channel optical/IR imager)
0.9m telescope + 2K CCD

We will bring the Yale 1.0m telescope on-line later, and a variety of instrument upgrades are planned. Each of the telescopes will be operated in a different manner, to enable different kinds of science to be carried out. The 1.3m will be operated in queue observing mode, with the queue created daily in New Haven, and executed by on-site observing technicians. This is a continuation of the YALO program, which has used the same instrument on the Yale 1m telescope since 1998. We have found that by updating our queue daily in response to the previous nights observing and to rapidly changing astronomical phenomena, we are able to create unique synoptic data sets of considerable importance - it is this success that has led to the formation of the much more extensive SMARTS operation.

We hope to develop a similar queue-based synoptic operation for the 1.5m and its spectrograph. However, spectroscopic monitoring is considerably more complex than imaging, so we intend to start with a primarily block-scheduled plan, and conduct a variety of experiments leading to a fully queue-scheduled operation by the end of the 3-year SMARTS project. The 0.9m (and later the 1.0m) will operate in a mixed mode - week long service observing blocks will alternate with week long block-scheduled runs where the astronomer will be present.

Our scheduling of YALO was done entirely "by hand". However the more complex SMARTS operation would clearly benefit from automated tools of the type being developed by the SGM group, and more generally by a careful review of our rather ad hoc current procedures. Since part of the SMARTS mission is to explore non-standard operations and scheduling modes, we welcome the proposed collaboration with the SGM group.

THE OHIO STATE UNIVERSITY

Department of Astronomy

140 West 18th Avenue
Columbus, OH 43210-1173

Phone 614-292-1773
FAX 614-292-2928
www.astronomy.ohio-state.edu

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To Whom It May Concern:

I am writing in support of Science Goal Monitoring (SGM) proposal that is being prepared by Dr. Anuradha P. Koratkar of the Space Telescope Science Institute. I am the Principal Investigator for *Kronos,* a Medium Explorer (MIDEX) concept that will be submitted to NASA during the next competition in approximately 15-18 months. *Kronos* is a high-Earth orbiting multiwavelength observatory to study the environments of black holes and other accretion-driven sources by using timing-based methodologies. *Kronos* is designed for high time resolution, long duration monitoring.

Kronos would be an excellent test bed for the SGM concept: our targets are variable, and we need to assess on rapid time scales changes in the science program, from changing integration times to achieve optimal signal-to-noise ratios at each visit to accommodating targets of opportunity into our observing schedule.

We envision a phased implementation of the SGM tool on *Kronos*, as described in the proposal:

(1) We will first run the tool on the ground, in parallel with manual scheduling, to determine if the system results mimic the manual results.
(2) When the results of step (1) are satisfactory we will run the tool on the spacecraft. In this phase it will not be fully implemented, but will report the results it would have chosen to do if it were implemented.
(3) inally, once we are satisfied with step (2) we will fully implement the tool on the spacecraft.

This will be an extraordinarily valuable tool for variability studies with *Kronos*. It will undoubtedly have wider applicability in the future, and we will be happy to participate in this study if *Kronos* is selected for flight.

Sincerely yours,

Bradley M. Peterson
Professor of Astronomy
Principal Investigator, *Kronos* Project